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Variation and Selection: The Evolutionary Analogy and the Convergence of Cognitive and Behavioral Psychology

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The empirical and theoretical work of both operant and cognitive researchers has increasingly appealed to evolutionary concepts. In particular, both traditional operant studies of extinction-induced behavior and cognitive investigations of creativity and problem solving converge on the fundamental evolutionary principles of variation and selection. These contemporary developments and their implications for the alleged preparadigmatic status of psychology are discussed.

Key words: variation, selection, evolution, problem solving, creativity, extinction

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The concept of selection and the evolutionary analogy in general have received considerable attention in recent works on operant psychology (Catania & Harnard, 1988; Richelle, 1987; Skinner, 1981, 1984). Acknowledgment that the similar processes of variation, selection, and retention characterize both natural selection and the reinforcement of ontogenic behavior seems at this time unavoidable. Indeed, in discovering this principle of evolution writ small, operant psychologists may well have stumbled upon precisely the kind of conceptual paradigm whose historical absence has been lamented both by operant and nonoperant psychologists (e.g., Giorgi, 1976; Staats, 1981).

The distinguishing characteristic of a paradigm, however, is its capacity to account for large volumes of empirical data, garnered from a heterogeneous subject matter, and collected by researchers representing discrepant theoretical and methodological orientations. Do operant psychologists constitute a minority in recognizing the utility of evolutionary concepts in accounting for their subject matter? There appears to be no compelling evidence that this is the case. For example, many cognitive psychologists, particularly those studying creativity and problem solving, embrace an evolutionary model of cognition that, minus some organismic language, bears a striking resemblance to operant accounts of complex human behavior. Indeed, having negotiated the inevitable differences in terminology employed by cognitivists and behavior analysts, one is struck by the prominence of such themes as variation and selection in these otherwise disparate world views.

In many ways, it is fitting that behavior analysts entertain such concepts as problem solving and creativity, for they represent precisely the kinds of behavior to which operant theory is said to be inapplicable. This claim may in fact be a half truth, because to date operant psychologists have had little to say about such phenomena (see Skinner, 1966, for an exception), but this state of affairs needn't be considered inevitable. Operant psychology may be quite adequately poised, both conceptually and experimentally, to deal with such complex human behavior. Doing so, however, entails a lengthy process of reeducation and

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a familiarity with a literature divergent from behavior analysis, tasks likely to be perceived as burdensome by the researcher (Miller, 1983). Such an endeavor frequently entails some "unpacking" of the concept, distinguishing its many uses and interpretations, and the methods used by researchers to investigate its empirical parameters (Harzem & Miles, 1978). The researcher is then faced with the challenge of deciding whether to use previous methods of research or more familiar operant tactics (e.g., schedule research) to study the phenomenon, and, perhaps most difficult, interpreting empirical results within an operant theoretical framework. The objective of the present paper is to suggest a possible course that such an analysis might take and to examine how both basic operant research and cognitive explanations of problem solving and creativity converge upon the evolutionary principles of variation and selection.

PROBLEM SOLVING AND CREATIVITY

A student in a cognitive psychology course is not likely to leave the course ignorant of such classic tasks as the water jug (Luchins, 1942) and candle problems (Duncker, 1945). In the former task, the subject is given three jugs, each containing or capable of containing a specific amount of liquid, and is asked to come up with a jug containing a particular quantity. This task normally entails some combination of filling and emptying of the three jugs, thus representing a problem to be solved by the subject. Frequently it is discovered that a subject with a history of solving the water jug problem in a particular way will continue to apply this strategy even when a simpler method would succeed, manifesting what cognitive psychologists call a "perceptual set."

Duncker's (1945) candle problem requires a subject to mount candles on a wall, given only a box containing matches and another containing thumbtacks. The candle problem is usually presented within a discussion of "functional fixedness," because the primary dependent measure is whether the subject will perceive that the box containing the matches or thumbtacks can be used for other purposes, say, as a platform on which to set the candle.

Somewhat more recently, cognitive researchers have used the nine-dot problem, in which subjects are required to connect nine dots together using four straight continuous lines, without lifting the pen or pencil from the paper (Burnham & Davis, 1969; Weisberg & Alba, 1981). The nine-dot problem is often thought to be problematic due to the subjects' inability to perceive the connecting line as being drawn outside the square-like configuration suggested by the matrix of dots.

Of course, psychologists have been requiring subjects to solve problems for more than six decades, and it was within the context of problem-solving research with primates that the Gestalt school of thought emerged as a seductive alternative to stimulus–response psychology (Kohler, 1925). Most behavior analysts are aware of the difficulties that "insight" learning was said to pose for a behavioral, trial-and-error account of problem solving. Indeed, the concept of "insight" seems indispensable to many of the original explanations of creative behavior. For example, Hadamard's (1949) classic interpretation suggested that the "insight" consistently emerging in major scientific discoveries follows from a predictable sequence of events: preparation, incubation, illumination, and verification.

"Insight," however, remains an especially troublesome concept in modern cognitive psychology, and in fact plays no explanatory role in much contemporary theory in creativity and problem solving (Dominowski, 1981; Weisberg & Alba, 1981). Weisberg (1988), for instance, holds a "nothing-special" view of insight, arguing that creative ideas do not emerge from a contextual vacuum, but instead come from a rich mosaic of experience that may remain inconspicuous both to the creative person and, problematically, to the observing scientist. Interestingly, several behavior-analytic explorations of infrahuman problem solving appear to converge on the same conclusions (see, e.g., Epstein, 1985, 1987).

The literature of creativity contains almost as many definitions of the concept as there are scholars in search of its nature. Taylor (1988) has provided an impressive, though perhaps not exhaustive, compilation of definitions of creativity utilized over the years by researchers. Although such definitions demonstrate considerable theoretical heterogeneity, it is possible to extract from them some essential commonalities. Torrance (1988), for example, observes that most definitions of creativity refer to the production of something new, whether in the form of behavior, a physical object, or the solution to a problem. This particular definition coincides not only with its vernacular usage but also with much of the experimental literature on creative behavior. Moreover, the definition seems to pose few problems for a behavior analysis of creativity.

Many traditional efforts to describe and explain creativity have emerged in the context of explaining significant achievements by artists or scientists. Einstein's conception of space and time, Darwin's recognition of natural selection as the key to evolution, and Watson and Crick's discovery of the structure of DNA are all considered to epitomize the role of "genius" in scientific discovery. Within the traditional literature, the characteristics of the "creative person" have received a sizable share of research attention. For example, a volume edited by Sternberg (1988) lists no fewer than nine separate tests designed to measure some aspect or aspects of creativity. Nor has there been a shortage of research aimed at discovering possible personality correlates of creativity (e.g., Tardiff & Sternberg, 1988). However, to conclude that creativity researchers have neglected entirely the circumstances under which creative behavior develops would be a mistake. Instead, their efforts to conceptualize the "creative process" frequently have been stated in terms behavior analysts would find appealing.

Creativity researchers also exhibit a fascination with the interesting phenomenon known as "multiples," in which major discoveries are happened upon by more than one person simultaneously. Such events were a constant source of intrigue to E. G. Boring (1950), who, not coincidentally, wrote extensively about the antecedent conditions of "insightful" solutions to problems. The most celebrated "multiple" in science was the simultaneous discovery of the calculus by both Newton and Leibniz. Such events provide substantial fodder for those who would debate the "great man" versus "zeitgeist" theories of scientific advancement. Boring opted for the plausibility of the latter of these hypotheses. He was convinced that the simultaneous occurrence of great ideas tells us more about the intellectual and cultural climate of the times than it does about individual genius. Certainly, the occurrence of "multiples" in science makes feasible the contention that certain conditions, be they past experience or current environmental events, serve as likely antecedents to creative behavior.

Yet another provocative theme runs through much of the current work on creativity. This view holds that creativity represents a selection process, in many ways similar to that occurring on the more distant plane of phylogeny. A problem solver is assumed to be engaged in a process of trying out, either overtly or covertly, a number of potential strategies, with the most successful strategy being retained, having been selected for its fitness (Gruber & Davis, 1988; Perkins, 1988). Perkins paints a picture of scientific discovery in which researchers bump up against "intransigent problems," apply potential problem-solving strategies, pull back when these strategies prove ineffective, then apply new alternatives, until, ultimately, a solution is reached. Such descriptions invite comparisons with Skinner's (1981) discussion of selection by consequences and the analogy to biological evolution. The problem solver encounters a problem, generates an array of potential solutions (response variation), applies these solutions until one meets with success (reinforcement), and consequently applies the fruitful solution strategy to similar future problems.

Problem solving is not the only research program in cognitive psychology whose data seem to reveal a selection process. For example, Marvin Levine (1966, 1970) utilized an ingenious procedure for making known the hypotheses used by human subjects during a discrimination task. Subjects were asked, on a trial-by-trial basis, to determine which of two stimulus figures, typically either of two letters, such as "X" or "T," was the correct letter on a given trial. The figures differed on four dimensions, relative size (large–small), shape (X–T), color (black–white), and position (left–right). Individual stimulus cards contained both figures, but the relevant dimensions varied from trial to trial. Prior to each set of trials, the experimenter arbitrarily defined the "correct" dimension. The subject's task was to hypothesize which dimension (size, shape, color, or position) was correct, and to respond by pointing to the stimulus that, on a particular trial, met this criterion. The critical feature of the experiment was a series of "blank trials," during which the subject's hypotheses received neither confirmatory nor disconfirmatory feedback. By examining the sequence of responses to a series of stimulus presentations, the experimenters were able to identify which dimension was controlling responding during any particular series.

Levine (1966, 1970) demonstrated, among other things, that subjects retain hypotheses both subsequent to receiving confirmatory feedback and in the absence of any feedback. Disconfirmatory feedback resulted in the immediate abandonment of the incorrect hypothesis in favor of an alternative. In addition, Levine showed that new alternatives are selected without replacement; that is to say, ineffective hypotheses are not placed back into the pool of subsequently available hypotheses. Thus, correct hypotheses are selected through reinforcement and incorrect hypotheses undergo extinction, in a manner analogous to the process of shaping. Moreover, Levine's data corroborate findings from the operant laboratory attesting to the increased variability in responding produced by extinction (e.g., Antonitis, 1951; Eckerman & Lanson, 1969; Eckerman & Vreeland, 1973). In general, Levine's results strongly suggest a selection process that is similar to both the classic problem-solving tasks and a general evolutionary model of behavioral selection.

More recently, the neurobiologist William Calvin (1987, 1989) has speculated that many cognitive processes may entail a selection process governed by an underlying neurobiological "Darwin Machine," which "shapes up thoughts in milliseconds rather than millenia, and uses innocuous remembered environments rather than the noxious real-life ones" (1987, p. 33). To the extent that he has invoked an endogenous mechanism capable of generating behavioral variability, Calvin has embraced an explanation that would appeal to few behavior analysts. On the other hand, he has suggested an interesting vehicle for the spontaneous emergence of cognitions and a process of selection whereby the environment dictates the criteria for "fitness." It is interesting to wonder whether one could substitute the phrase "past consequences" for Calvin's "remembered environments" in order to render his conceptualization more meaningful to behavior analysts. What is ultimately useful in Calvin's account, however, is neither the physiological parameters nor the private status of his "Darwin Machine" but rather his suggestion that the mechanism operates according to fundamental principles of selection.

Nor has the relevance of a variation and selection model of behavior gone unnoticed by philosophers of science. Dennett (1975), for example, speculates that the popularity and historical persistence of the law of effect in psychology are due largely to its functional resemblance to natural selection. And, according to Popper (cited in Pickering & Skinner, 1991):

> We may consider that natural selection will favour those organisms that try out, by some method or other, the possible movements that might be adopted before they are executed. In this way, real trial and error behavior may be replaced, or preceded, by imagined or vicarious trial and error behavior. (p. 114)

It is but a small step to envision how generic processes of selection warrant consideration at the hands of behavior analysts. The idea that the environment selects response classes through reinforcement in a manner similar to the natural selection of morphological characteristics is both inviting and parsimonious. Merely noting the appropriateness of the evolutionary analogy, however, is but a first step. Its ultimate utility to operant researchers has yet to be fully explored. Behavior analysis historically has been devoted to but one of these components—the process of selection through reinforcement—a fact attested to by Catania and Harnard's (1988) recent collection of Skinner's writings. But selection must by necessity operate against a background of variation. Natural selection makes little sense as a process in the absence of genetic variation brought about by mutation and sexual recombination. Similarly, it is a truism, perhaps most appreciated by clinicians, teachers, and others charged with changing behavior, that a response must occur before it can be reinforced. However, as Plotkin (1987) has observed, operant researchers often have presumed that operant classes are shaped from a larger universe of spontaneously emitted movements. Even for Skinner "there is always an element of mystery in the emission of any operant response. . . . In problem solving we generate conditions which make a solution likely to occur, but we cannot say exactly when it will occur" (1968, pp. 137–138).

Despite having afforded the selection process a disproportionate amount of research attention, operant psychologists have not been silent concerning the issue of behavioral variability. An interesting dialogue has recently developed in behavior analysis concerning the variability and stereotypy of operant behavior. On the one hand, it has been stated that operant conditioning experiments typically produce topographically stereotyped responding, despite contingencies that specify no such behavioral rigidity (e.g., Schwartz, 1980, 1982). Emphasizing the selective nature of operant conditioning, Schwartz (1982) argues that rigid and economical response classes are molded, through reinforcement, from a large and physically variable universe of movements. No one would deny that this essentially is the nature of the "shaping" process, but it is not clear from Schwartz's data that stereotypy is an inherent and inevitable consequence of operant learning. Page and Neuringer (1985) have presented a provocative argument that if variability is the behavioral parameter upon which reinforcement is made contingent, then variability can indeed be considered an operant response class. It is important to note, of course, that this variability may apply to any of a number of dimensions of behavior, including speed, intensity, response location, and so on. They further posit that organisms may possess a random generator capable of producing variable behavior, a notion suggestive of Calvin's (1987) neurological "Darwin Machine." An evolutionary model makes quite tenable the claim that organisms possess an endogenous, biological mechanism for generating behavioral variability. However, as behavior analysts have long contended, proposing the existence of an internal mechanism may serve to bring meaningful empirical analysis to a premature halt. Fortunately, behavior analysis may be in a uniquely qualified position to ask important subsequent questions. For example, assuming that such a mechanism exists, under what conditions is it pressed into duty? What sorts of contingencies might generate stereotypic, as opposed to highly variable, response classes? Clearly, the thrust of behavior-analytic work on this subject would be toward describing the conditions under which response variability occurs, and not toward describing the underlying architecture of the "Darwin Machine." We maintain, in fact, that some light has already been shed on such matters by both the classic and contemporary operant literature.

EXTINCTION AS AN ONTOGENIC SOURCE OF VARIABILITY

For both theoretical and methodological reasons, behavior analysts may not be receptive to the behavioral variability that arises within experimental conditions. This may be due in part to the fact that we place a considerable, and for the most part well-conceived, emphasis upon steady-state methodology (Johnston & Pennypacker, 1980; Sidman, 1960). This may be done at some expense, however, as when we view the steady-state condition as a behavioral optimum, the period following a "noisy" transition phase when the effects of an independent variable are rendered most conspicuous. Although behavior analysts may not entirely ignore the interesting metamorphosis that behavior undergoes during transition periods, the comparison of two steady states generated under different experimental conditions is a stimulus of an almost overwhelming salience for most of us. In foregoing an analysis of these trend-laden periods, are we eliminating a vital source of empirically and theoretically profitable data? An observation from the cognitive literature may help answer this question.

In studies of problem solving, cognitive researchers frequently conduct "protocol analysis," in which subjects are asked either to "think out loud" while trying to solve a problem or to remember solution strategies after working on problems. Although the methods of protocol analysis raise issues reminiscent of the problems associated with "introspection," some useful observations emerge from such research. For example, subjects in these studies have been shown to differ with respect to the strategies they use to solve the experimenter-imposed problems. Subjects generate and implement strategies, abandon those that prove ineffective, and retain for the future those that contribute to problem solution. The suggestion being made here is that "protocol analysis" can be conceptualized as the analysis of a period of disequilibrium similar to the transition periods during operant experiments. What are the operant parallels to such instances of "problem solving"?

When one considers the descriptions of subjects trying to solve the nine-dot problem, the candle problem, and the water jug problem in cognitive psychology experiments, it is difficult not to be reminded of the experimental analysis of extinction effects. The operant literature contains numerous examples of the partial-reinforcement effect (Humphreys, 1939; Robbins, 1971), extinction-induced aggression (Azrin, Huchinson, & Hake, 1966; Rilling, 1977), and, from both basic and applied research, extinction burst (Lovaas & Simmons, 1969; Neisworth & Moore, 1972). The latter two phenomena could readily be subsumed by the higher level phrase, "extinction-induced variability." Whatever else "aggression" or "burst" might imply, they represent variability in responding relative to a preextinction baseline. Ordinarily, this variability consists of increases in the intensity of the response or physical aggression directed at others in the immediate environment. Undergraduate students, observing a rat biting, sniffing, and otherwise pestering a rodent lever during extinction, couch their explanations in a language the behavior analyst may find distasteful, yet it is instructive. The rat may variously be credited with "trying to find out how to get the foot back" or "discovering" why the food no longer follows lever presses; in essence, it is solving an experimenter-posed problem. Although we may instruct the students as to the pitfalls of anthropomorphism, they are not wrong for having observed the similarities between the rat's behavior when a previously reinforced response is extinguished and the human subject's miscues in solving, say, the nine-dot problem. In either case, response variability appears to have been engendered by a change from reinforcement to extinction. It is relatively unimportant, on theoretical grounds, whether "lever pressing" can be equated topographically with "solving the nine-dot problem" (Harzem, 1986).

The extent to which response variability increases during extinction has been well documented in the operant literature. A number of response properties, including temporal and sequential organization (Millenson & Hurwitz, 1961; Stebbins, 1962; Stebbins & Lanson, 1962), force (Notterman, 1959), and location (Eckerman & Lanson, 1969; Ferraro & Branch, 1968), become more variable during extinction relative to a prior reinforcement condition. Moreover, investigations of schedule effects further suggest that intermittent reinforcement engenders greater variability in many response properties than does continuous reinforcement (e.g., Herrick & Bromberger, 1965; McSweeney, 1974; Stebbins & Lanson, 1962).

Extinction, then, may under certain circumstances be a significant determinant of behavioral variability. Such variability can be highly adaptive during problem-solving tasks if responses eventually emerge that fulfill requirements for reinforcement. In fact, Epstein (1985, 1987) has claimed that the development of "insightful" solutions to problems may result from an extinction process in which numerous singularly ineffective responses become synthesized, a process he refers to as "extinction-induced resurgence." Antedating this notion, Campbell (1960) asserted a "blind-variation and selective-retention" account of creativity, arguing that many problems are solved only after continuous failure, when new, topographically novel response alternatives develop. Moreover, Campbell sees the essential process as relevant not only to human problem solving but also to basic sensory-perceptual processes and to phenomena such as exploratory locomotion in paramecia and earthworms. And in a statement reminiscent of Skinner's (1963) claim that the analysis of operant behavior is the study of purposeful behavior, Campbell states, "Like the theory of natural selection in organic evolution, it provides an understanding of marvelously purposive processes without the introduction of teleological metaphysics or of pseudocausal processes working backward in time" (1960, p. 396).

There are, naturally, other sources of behavioral variability, including imitation and instructional control, the latter having evolved as a subject matter within behavior analysis (e.g., Buskist, Bennett, & Miller, 1981; Shimoff, Catania, & Matthews, 1981). In addition, a contingency that specifies variability as the criterion for reinforcement can itself engender variable responding (Page & Neuringer, 1985; Pryor, Haag, & O'Reilly, 1969). The apparent generality of extinction-induced variability, however, seems to make it a promising candidate for further analysis. As mentioned previously, many human activities ordinarily overlooked by behavior analysts, including hypothesis testing and conceptual behavior, creativity, and problem solving, strongly resemble extinction-induced phenomena. Philosophers of science have remarked that powerful concepts are those that prove capable of accounting for and integrating presumably disparate or unrelated phenomena (Kuhn, 1962). Extinction-induced variability may be just such a concept, because it compels comparison not only with cognitive accounts of complex human behavior but also with the fundamental principles of evolutionary theory.

In many ways, the methods for investigating extinction-induced variability are already in place. We have been generating data on the subject for as long as we have been studying schedule performance, stimulus control, and extinction itself. However, we have not ordinarily seen the variability generated by changes in contingencies as our dependent measure. We have attended more to where such transition periods ultimately lead than to the process by which they arrive. At least for the purpose of studying extinction as a variability-inducing process, perhaps our perspective requires more change than does our methodology.

CONCLUSION

Richelle (1987) has noted that the evolutionary analogy, although perhaps not fully utilized, was recognized by Skinner as early as 1953. The theme was to resurface frequently during the last three decades of his life (Skinner, 1966, 1981, 1984). What is not yet apparent, however, is whether the analogy will prove useful to behavior analysis, and if so, in what capacity.

We have suggested that the analogy may permit a successful integration of research data from both cognitive and operant psychology. To the extent that extinction and reinforcement processes engender variation and selection at an ontogenic level, the analogy appears to hold some integrative promise. However, in addition to noting the potential parallels between problem solving, creativity, and extinction-induced behavior, a more thorough analysis of the cognitive literature seems warranted. We would like to know whether the details of the behavior in such experiments strongly resemble findings in the extinction literature. In addition, several questions remain concerning the data base of extinction-induced variability in the operant literature. There is, for example, the matter of describing the specific topography of responding under extinction. In other words, of what does this variability consist? Is behavior at this time best described as random topographic variation, or, as Epstein (1985, 1987) has suggested, do previously reinforced response classes emerge during extinction? What is the extent of the variability relative to baseline responding, and what kind of history may account for individual differences in the expression of extinction-induced variability? If variability during extinction can be said to have adaptive value as a problem-solving heuristic, to what extent can this form of "creativity" be encouraged? These questions seem to be especially pertinent to human behavior, and they remain essentially unanswered in the predominantly nonhuman animal literature.

Pursuing the evolutionary analogy from a behavior-analytic perspective may take many forms. Much of the history of operant research has been devoted to the selective properties of reinforcement and punishment. We have suggested, however, that the operant literature on extinction may be similarly relevant to this pursuit. In addition, the study of extinction-induced variability may hold potential promise not only for behavior analysis but also for the larger conglomeration of epistemology, theory, and method that is psychological science. For scholars who trace psychology's current ills to its preparadigmatic status as a science, the integrative prospects of extinction-induced variability should be good news indeed.

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